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ANALYSIS OF THE PRODUCTION PLANNING AND INVENTORY CONTROL SYSTEM USED BY NADEP, NORTH ISLAND FOR THE REPAIR OF THE T-64 SERIES ENGINE

by

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Analysis of the Production Planning and Inventory Control System used by NADEP, North Island for the Repair of the T-64 Series Engine

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

This thesis is an analysis of the current production planning and inventory control system used by NADEP, North Island for the repair of the T-64 series engine. The system is described and analyzed for its effect on repair time and work-in-process inventory. Recommendations are made to improve repair time and reduce work-in-process inventory levels. A simulation and queueing theory are used to compare the queue of awaiting maintenance engines under the current system versus the queue when a specified monthly repair rate is maintained.

TABLE OF CONTENTS

I. INTRODUCTION

This thesis is an analysis of the current production planning and inventory control system used by Naval Aviation Depot, North Island for the depot level repair of the T-64 series engines.

The thesis will be divided into seven chapters and two appendices. Chapter I will present background information, scope of the research question, methodology, and will identify benefits that can be derived from the study. Chapters II and III describe respectively the facility layout and the flow of material through the production process. The current production scheduling and control system is presented in Chapter IV along with an analysis of its impact on the repair process. Recommendations based on the observations presented in Chapters III and IV are the subject of Chapter V. In Chapter VI a simulation and queueing model will be used to demonstrate the effects of different maximum repair rates on the awaiting maintenance queue. The final chapter will give conclusions and recommendations for future work in this area. Appendix A provides the framework for the analysis. Three prominent production planning and inventory control systems currently used by industry are presented and compared. Anyone not very familiar with MRP II, Toyota's Production System, or

OPT should read Appendix A. References will be made to them and the philosophy behind their operations throughout the thesis. Appendix B contains any data used in the thesis and not presented in the body of the text.

A. BACKGROUND

Repair of aircraft engines impacts the Navy in two primary areas: 1) operational readiness, which is partially a function of asset availability, and 2) cost, which includes both the costs associated with holding inventory, and repair costs.

Availability of ready for issue (RFI) engines is directly related to fleet readiness. As measured by asset availability, fleet readiness is a function of the degree, percent or probability that an asset will be available when required for use. For a given total number of engines in the system, reduction in the mean time to repair will increase availability of the asset and therefore readiness.

Cost has three principal components, annual inventory, investment, and repair costs. Inventory costs include both ordering costs, and the costs incurred in holding inventory which are primarily associated with physical storage and materials handling. Investment cost is the actual cost of the asset. Annual inventory and investment costs then are directly related to the amount of inventory procured and held. The total level of inventory in the system includes both RFI assets and non-RFI assets in the repair cycle.

Inventory levels in the repair cycle are a function of mean time between failure (MTBF) and mean time to repair (MTTR). By reducing MTTR inventory held in the repair cycle will decrease. This could lead to a reduction in total system inventory and direct cost savings for the Navy.

The other cost element that can be reduced is the repair cost. Efficient management of the production/repair process will lead to minimization of repair time and costs.

B. SCOPE OF THE STUDY

The thesis will focus on the flow of a T-64 engine through its repair process at Naval Aviation Depot, North Island. The study will involve an assessment of the process as it is currently performed. The assessment will be limited to material flow and production control procedures which will be described and analyzed for their impact on the repair process.

The study will then demonstrate, through simulation and queueing theory, the effects of maintaining maximum monthly repair rates of eight, nine, and ten on current inventory levels of both RFI and non-RFI engines.

C. RESEARCH QUESTIONS

Five questions will be explored:

1. What is the current flow of material through the facility?

2. How are repairs scheduled and the process controlled?

3. What is the impact of the current process on repair time and work-in-process inventory levels?

4. How will reduced repair time impact the current level of total system inventory?

5. How does production rate affect total system inventory?

D. METHODOLOGY

A review of current literature relating to production planning and inventory control systems, historical data, actual observation, and interviews with planners, shop foremen and workers will be used to perform the analysis.

Actual observation of the process, interviews with planners, shop foremen and workers, and the information from the literature will provide the foundation for describing and analyzing the repair process.

Historical data, taken from the T-64 engine planners weekly engine status reports and the aircraft engine management system (AEMS) will then be used to simulate the effects of different production rates.

E. BENEFITS OF THE STUDY

The study will provide a framework for analyzing depot level repair production planning and inventory control techniques. Direct benefits of this study will be the presentation of a method to reduce repair time and awaiting maintenance queues thereby reducing costs of repair and increasing availability of the T-64 engine and/or decreasing the total number of T-64 engines required.

II. FACILITY LAYOUT/WORK CENTER FUNCTIONS

To understand how materials flow through the repair process it is necessary to have an understanding of the facility layout and the functions performed within each work center. Physical layout is provided by Figures 1 and 2. Work center responsibilities are presented by dividing the facility into functional areas and then discussing which shops perform these functions.

A. DISASSEMBLY AND INITIAL ROUTING

Initial disassembly is the responsibility of the disassembly work center. This shop breaks the engine into its three basic sections of rotor assemblies, housing and combustion section, and accessories. Further disassembly as well as assembly of components is accomplished in their individual work centers. Rotor assemblies, the compressor case, and each accessory has its own work center.

Three persons are assigned to the disassembly shop. Two are responsible for the actual disassembly of the engine and one is an examiner/evaluator.

B. CLEANING

Chemical, sonic and steam cleaning is performed in work centers located adjacent to the disassembly shop. Manned by two people, the components of the engine that require

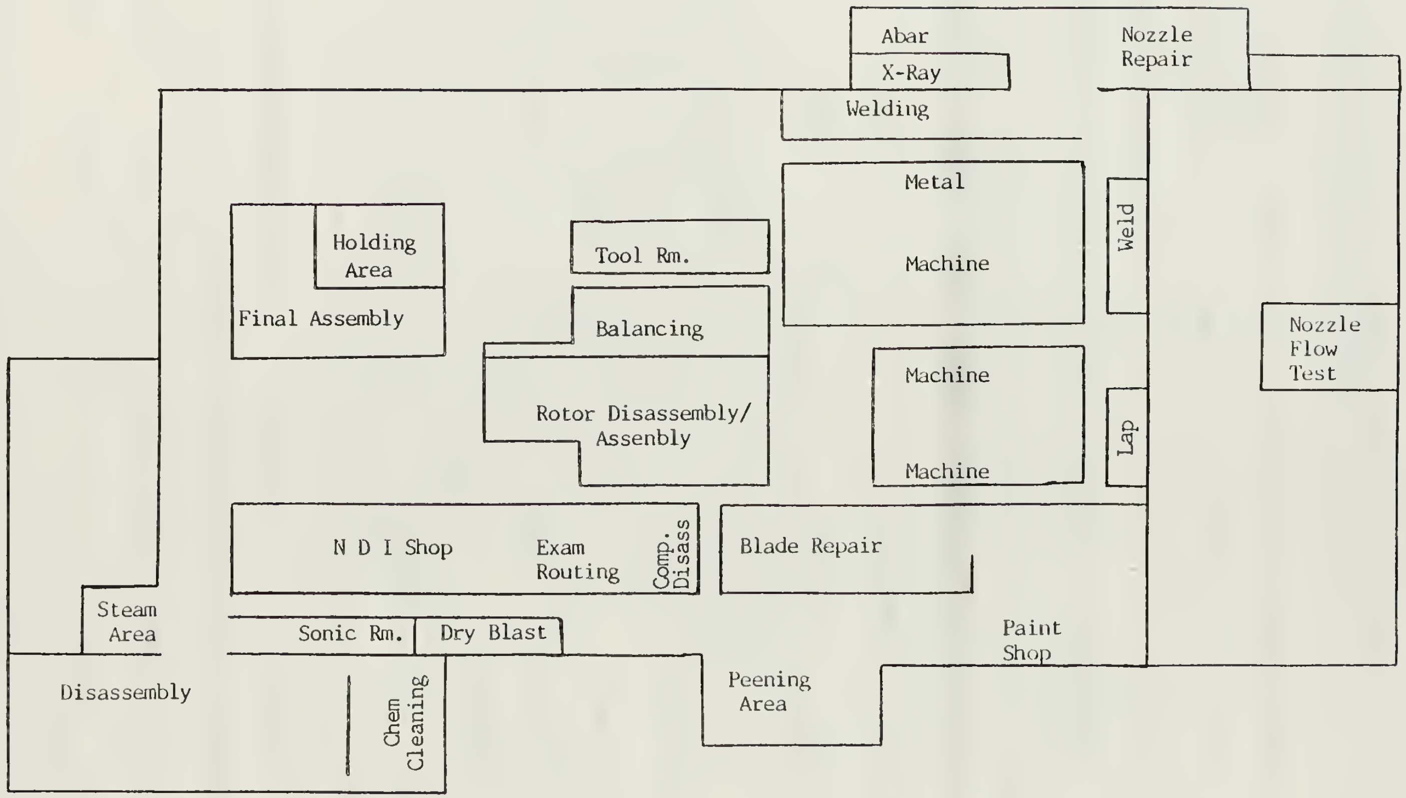

Figure 1. Lower Level Building 379 T-64 Engine Repair Facility

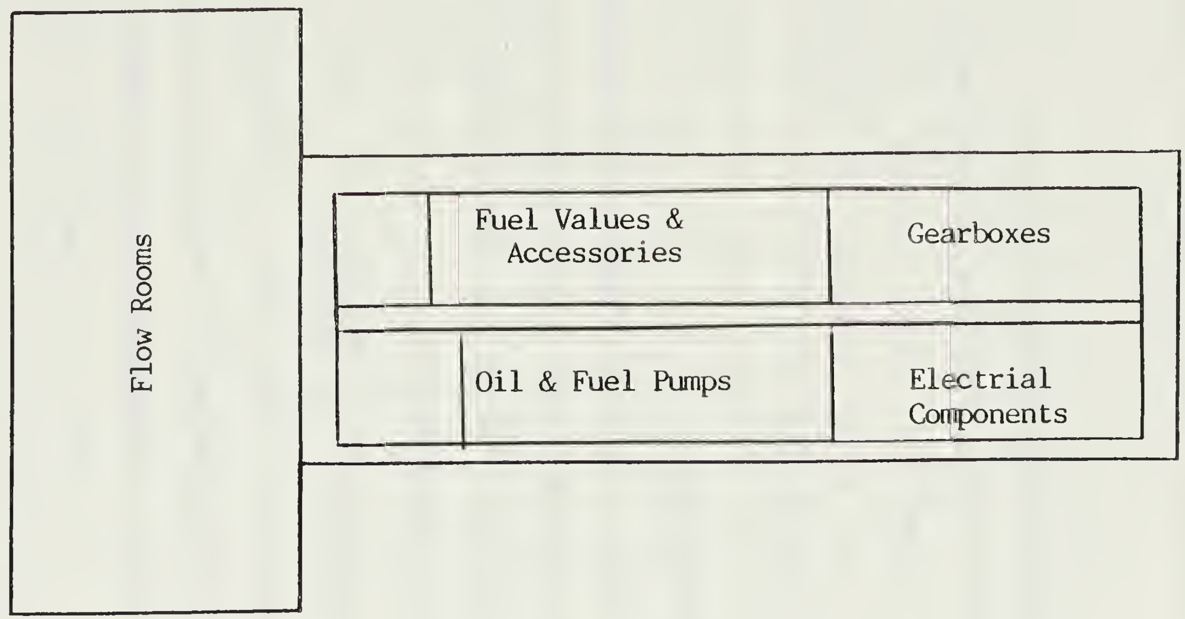

Figure 2. Second Level Building 379 T-64 Engine Repair Facility

cleaning are initially bulk processed in these work centers. Using baskets the parts are dipped in various chemical solutions and steamed as necessary.

Dry blasting is also available, however, this shop is manned by personnel from the chemical cleaning work centers as needed.

C. INSPECTION AND EVALUATION

Non-destructive testing is performed in the non-destructive inspection shop, manned by one person. The components are bulk dipped in penetrant, examined individually and routed.

D. PROCESSING SECTION

Metal repair, machine shop, surface treatment, nozzle repair and, welding shops are the work centers within this area. All metal work with the exception of plating is performed in these shops.

E. ROTOR DISASSEMBLY AND ASSEMBLY

Five persons man the rotor assembly/disassembly work center. Both the compressor and turbine rotor assembly are disassembled and reassembled in this shop. Additionally, dynamic spin balancing of completed rotor assembly is conducted by the work center.

F. BLADE RECONDITIONING

One person is assigned to the blade reconditioning work center. Blades from the compressor rotor, turbine rotor, and the stator vanes of the compressor case are processed in this shop.

G. PAINTING

Although the facility has a paint shop, no one is assigned permanently to this work center.

H. ACCESSORY REPAIR

Accessory repair is performed on the second deck of the facility. Individual work centers are established for electrical components, oil and fuel pumps, gearboxes, fuel values and accessories, and flow testing. A total of ten persons man the various shops, six assigned to disassemble and assemble, and four to flow testing. Repair of individual components of the various accessories is minimal. If a part is broken it is replaced by a new item.

I. ASSEMBLY

Buildup of the engine is performed by three people assigned to the assembly work center.

J. TESTING

Dynamic testing and final check of the engine is performed on test cells located about one quarter mile from Building 379. A complete check of the engine is performed

and any minor repairs or adjustments necessary are made at this work center.

K. CANNING/UNCANNING

T-64 engines are stored in climate controlled containers. Before induction and after repair, removal/replacement of the engine is accomplished by one person in an area adjacent to the disassembly area.

III. MATERIAL FLOW

This chapter will describe the flow of a T-64 engine and its various components through a repair or overhaul process. The process is analyzed by breaking it into three phases. The first phase will discuss induction, disassembly, evaluation, and preliminary routing. The second will present the processing of the three sections of the engine. The final phase will include final assembly and testing. Figure 3 is a flow diagram representing the overall process. Approximately four hundred components on the T-64 engine are processed by the facility in the course of a repair or overhaul. Those that are not processed are purchased through the supply system.

A. INTRODUCTION

Depot level repair of the T-64 series engine, which includes models 6B, 413, 415, and 416, is performed at Naval Air Depot, North Island. No significant difference exists between model types and all are repaired or overhauled on the same production line located in Building 379. All processes except metal plating and testing are performed at this site. Metal plating is done in Building 472 while testing is accomplished at special test cells located about one quarter mile from Building 379.

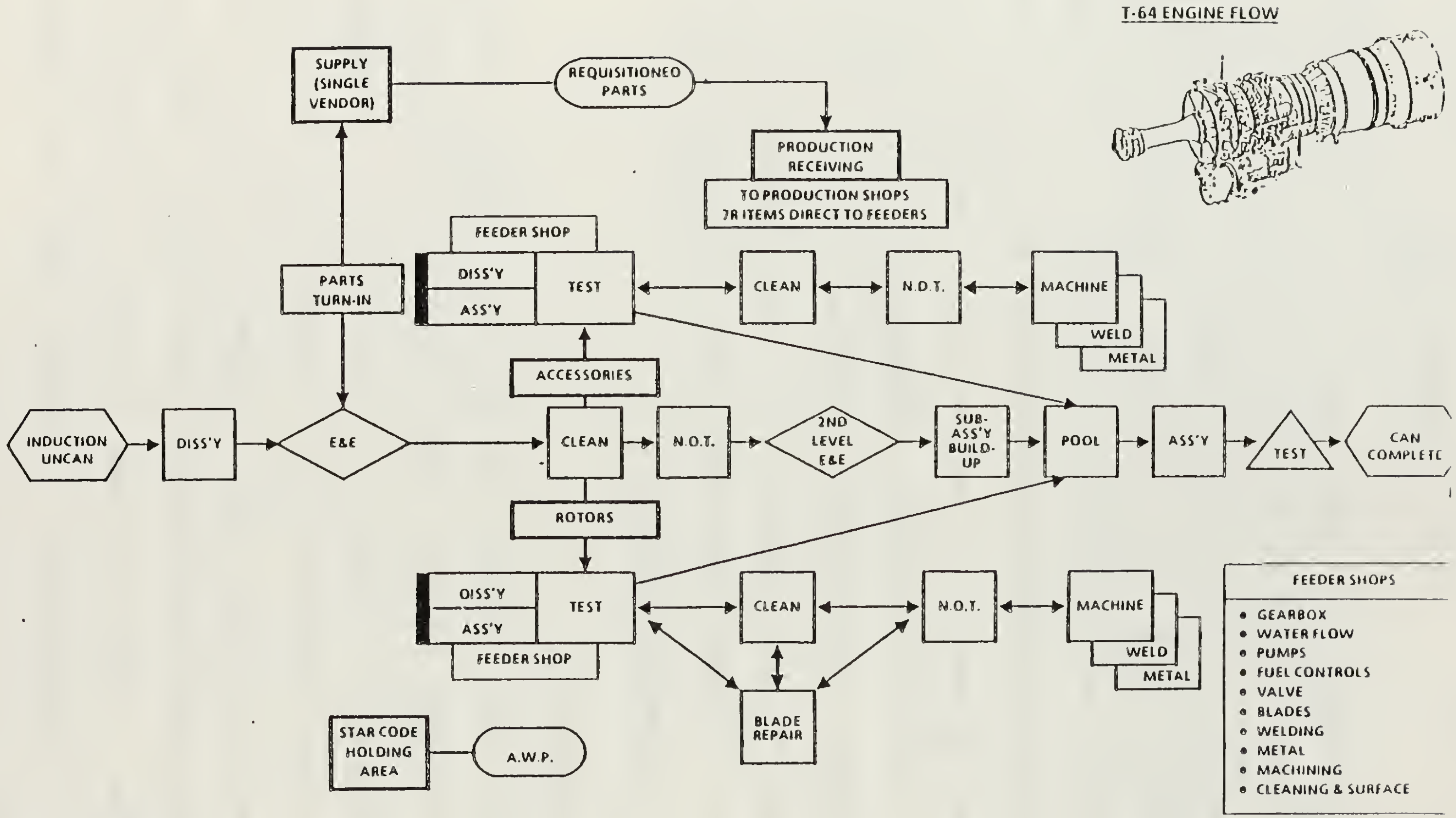

Figure 3. Material Flow Diagram

The facility performs work on two engines, the T-64 and T-58 series. Both engines share the cleaning, non-destructive testing, processing, accessory repair, and testing work centers. Independent shops are set up for rotor disassembly/assembly, blade repair, and final assembly.

B. PHASE I: INDUCTION, DISASSEMBLY AND EVALUATION, PRELIMINARY ROUTING

The first step in the production process is the uncanning of the engine. In this step the engine is removed from its storage container and placed in a maintenance stand. Next the engine is moved by tow tug into the disassembly work center.

Preliminary disassembly, examination, and evaluation are performed next. The engine is disassembled into three basic sections, 1) the rotor assemblies, 2) housings and combustion section, and 3) accessories.

The rotor assemblies, which include the compressor, gas generator, and power turbine rotors, are removed from the engine as whole sub-assemblies at this stage. They are then examined, evaluated and routed.

The housing and combustion section is composed of the front and exhaust frames, the compressor case, and the combustion section which includes nozzles, burner cans and casings. The combustion section is disassembled into its sub-components and then examined and evaluated while the

other assemblies are examined and evaluated before being disassembled.

The accessories, which include the fuel pump, fuel control, actuators, exciter, lines (fuel, lube, and air), lube pump, gearbox, and anti-ice valves are removed as sub assemblies and examined and evaluated.

Initial routing of the sub-assemblies and component parts is performed after preliminary examination. Evaluators determine which items need processing and route them accordingly. This routing includes the initial chemical, sonic and steam cleaning (whichever is applicable) of all parts processed. Those items that are not routed are placed on a holding cart. Each engine has its own cart and parts are accumulated on it as they complete processing.

C. PHASE II: PROCESSING OF BASIC SECTIONS

Components in this phase follow three different paths which correspond to the three basic sections into which the engine has been disassembled. In describing the flow of parts through the production process each section will be addressed separately beginning with the rotor assemblies followed by the housing and combustion section and lastly the accessories.

1. Rotor Assemblies

After preliminary cleaning the rotor assemblies are taken to the rotor disassembly/assembly work center. Here

the compressor, gas generator, and power turbine rotors are disassembled and their components are routed.

All rotor blades are pre-examined. Those not immediately rejected are then routed for cleaning. Following cleaning the blades are non-destructively tested and re-examined. Blades needing rework are then sent to the blade reconditioning shop.

The other components of the rotor assemblies are sent directly to the cleaning work centers followed by non-destructive testing. These are then examined and routed through the necessary work centers in the processing section.

As the processing of the individual parts of the rotor assemblies is completed they are returned to the rotor disassembly/assembly work center and stored in containers, each rotor having its own container. When all the parts of a rotor have been processed it is assembled and balanced.

The completed rotors are then placed on their respective engine holding carts.

2. Housing and Combustion Section

With the exception of the compressor case and fuel nozzles all of the components in this section are routed to the non-destructive inspection work center. Each part is inspected and if any defect is found it is routed to the appropriate work center in the processing section for repair. If necessary the component is again sent to the

non-destructive inspection work center before being moved to its engine holding cart. All components that pass the initial inspection are sent directly to the engine holding cart.

The compressor case is routed to its disassembly/assembly work center where it is broken down. Each component is then sent to the non-destructive work center for evaluation. Stator blades needing repair are routed to the blade repair shop while the case is sent to the processing section for repairs if necessary. After all components are processed the case is assembled and sent to the engine holding cart.

Fuel nozzles are flow tested to determine if repair is necessary. If needed they are routed to the nozzle repair shop, repaired and sent back to be flow tested again. After passing the flow test the nozzles are sent to the engine holding cart.

3. <u>Accessories</u>

Each accessory is first tested for correct performance. Only those components which fail dynamic testing are routed for repair. Repair of these components is limited to replacement of defective parts. After repair they are again tested and routed to the appropriate engine holding cart.

D. PHASE III: FINAL ASSEMBLY AND TESTING

After all assemblies and components are received at the RFI pool area where the engine holding carts are stored the

final assembly of the engine begins. Upon completion of buildup the engine is moved to the test cells.

Each engine is dynamically tested to ensure that it meets minimum performance standards. All minor adjustments and corrective actions are performed at this point. Upon completion of testing the engine is returned to Building 379 for canning.

E. SUMMARY

The T-64 engine repair facility is a product-focused repetitive manufacturing operation. Components flow through the facility in three distinct lines from disassembly to the final assembly work center.

IV. PRODUCTION SCHEDULING AND CONTROL

This chapter will present the current production scheduling and control system in use at the T-64 engine repair and overhaul facility. Each will be described followed by an analysis of their impact on the repair/overhaul processing time and work in process inventory levels.

A. SCHEDULING

A determination of the total number of engines that are to be scheduled for repair or overhaul is done by the Naval Aviation Depot Command, NADOC. They base their calculations on an estimate of the number of flight hours scheduled to be flown by aircraft that use the T-64 engine and the estimated number of failures per flight hour. Additionally, the NADOC can be constrained by fiscal requirements. That is, DOD funding levels for engine repair can be less than the amount needed to repair estimated failures. Table 1 below shows NADOC induction schedule by quarter for fiscal years 1986 through 1988. As can be seen, scheduling is segregated by series types. Since no significant difference exists in the way engines are processed, total engine inductions per quarter have been used for purposes of this study.

Facility engine planners, who control the T-64 engine repair process, use the numbers given them by NADOC and

TABLE 1

T-64 ENGINE INDUCTION SCHEDULE

	Fy 86/Quarter				Fy 87/Quarter				Fy 88/Quarter			
Model	1	2	3	4	1	2	3	4	1	2	3	4
6B	14	14	14	16	9	7	13	11	9	8	13	11
413	7	6	4	11	6	7	7	6	9	5	7	11
415	2	2	3	4	1	3	4	4	3	3	3	2
416	2	2	5	6	4	6	5	7	5	3	7	6
Totals	25	23	26	37	20	23	29	28	26	19	29	28

schedule inductions into the facility. Using a level loading policy, they divide the number per quarter by three to arrive at a monthly master production schedule.

The use of a level loading capacity plan has many advantages, all of which promote low production costs. The continuous flow of materials that occurs in level loading eliminates start up and shutdown costs. The costs of hiring and training new workers, as well as overtime and layoff costs are minimized when production rates are smoothed. Additionally, supervision is simplified and scrap rates are low when a continuous experienced work force is employed. Expedited orders, that can occur when production rates increase and decrease sporadically, are reduced and as a result material cost are minimized.

The advantages of level loading make it good policy for the NADEP to follow in capacity planning. However, the leveling should be based on repairs per month versus

inductions. This point will be discussed more fully in Chapter V.

B. PRODUCTION CONTROL

Repair/overhaul processing time is controlled by the rate of processing of each individual work center. Components, after induction, are pushed through the facility from work center to work center without an overriding master schedule or a completion due date. Figures 4 and 5 show average repair and overhaul schedules, but these are not used to control production or set priorities within work centers. Processing of components is done on a first in first out basis.

During disassembly shop order cards, Figure 6, are attached to each component. These are annotated by the evaluators and indicate what repairs are needed and the order in which they are to take place. As repairs are completed, components are moved to the next work center indicated on the shop order card. When all work is completed on an individual component it is moved either to its engine holding cart or to a RFI pool in the work center where its subassembly is built up. A bill of materials is annotated indicating receipt. Individual items are stored in their respective work centers in bins or on carts until the bill of materials is completed. Subcomponents are then assembled and placed on their respective engine holding

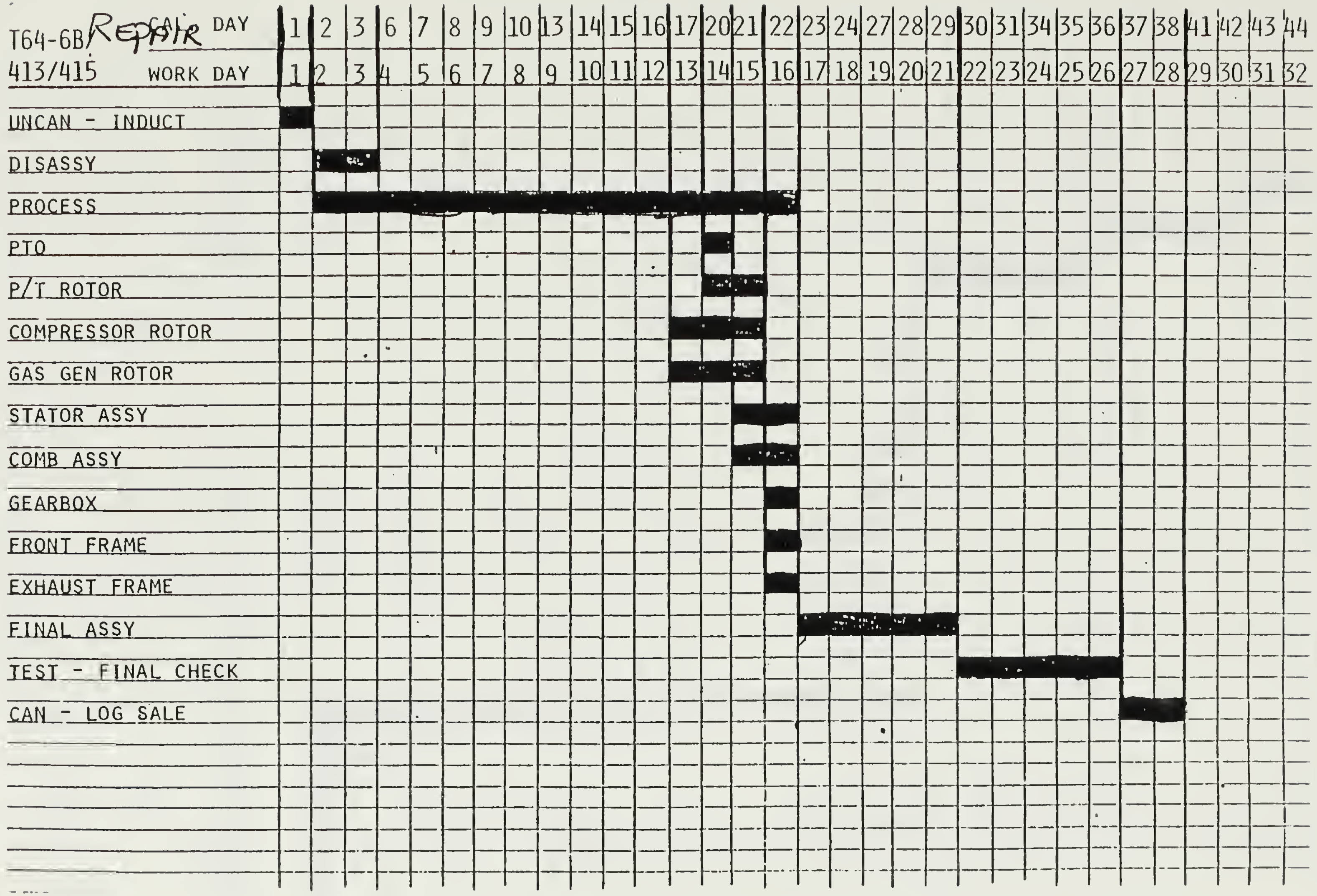

Figure 4. Repair Schedule

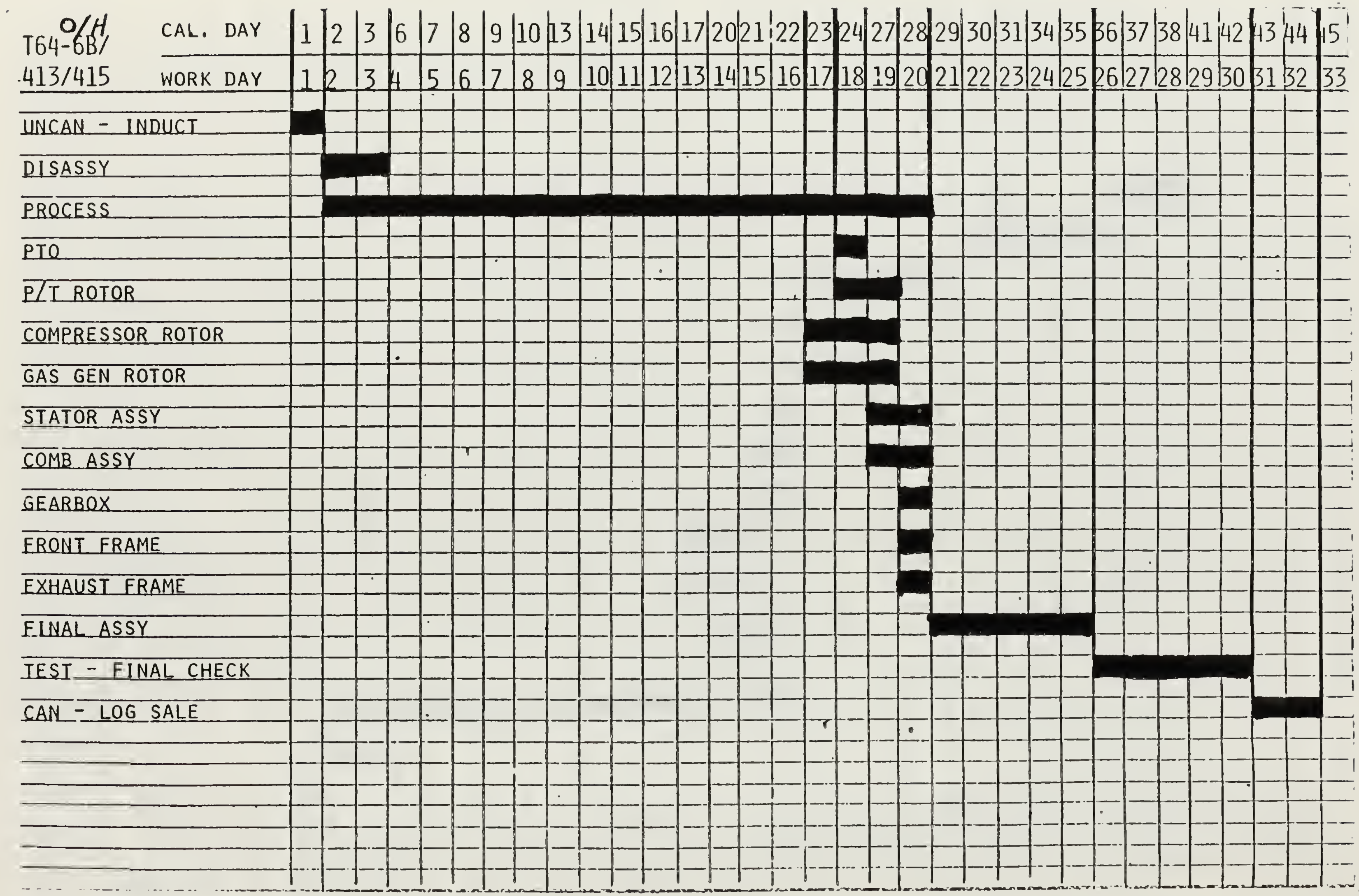

Figure 5. Overhaul Schedule

SHOP ORDER - UDAPS FOR INAS
NAVAVNDEPOT NI 4710/81 (REV 8-87)

PROGRAM 2 (ENGINES)

JN 25W0100 OA D1W MS 100 U98 77 574

LINK NO	PART NAME	RELATED DESCRIPTION	MOR CONTROL CODE	COMPONENT IDENTITY NO	PAGE
U987757	HOT-SECT	NI	2W000	A2DDDD400000	1

PRODUCT STD	CL	DISP CODE	TMS NAME	SEQUENCE	INDUCTED NATIONAL STOCK NUMBER	MODIFIED NATIONAL STOCK NUMBER	QUANTITY
		BW	413T64	W000			1

PROCUREMENT COST	MODEL CODE	MANUFACTURER'S PART NUMBER	PUBLICATION NUMBER	SPARES	BU NO
		MISC-PARTS	02B-105AJA/B		264000

LINE NO	SHOP NO	GEO AREA	SHOP CAT CODE	START DAY	COMP DAY	MHC	OPERATION CODE	STD CD	OPERATION STANDARD	OPERATION DESCRIPTION	SUPERVISOR INSPECTOR
02	52560	Q	44	016	016	4	AA01	C		E/E	
	42000		69							OCL-NO OCL	
04	93112	Q	MX	016	016						
	51610	Q	CX	027	027					79	
06	93112	Q	CF	028	028		0001			76	

LINK NO	PART NAME	UNIFORM DATA CLASSIFICATION CODE STRUCTURE	COMPONENT IDENTITY NO	PAGE
U987757	HOT-SECT	25W0100-3-TNNA-U9877574	A2DDDD400000	1-1

LINK NO: U987757

SEQ NO: W000

PART NAME: HOT-SECT

CIN: A2DDDD400000

PART NO: MISC-PARTS

Figure 6. Shop Order Card

carts until all engine subassemblies have been received. At this point the engine begins final assembly.

Final assembly is, therefore, controlled by the component or components which take the longest amount of time to be "pushed" through processing.

By using this "pushing" type production system the facility experiences longer than necessary repair time, which fluctuates continually, and a buildup of work-in-process inventory. These are the same problems encountered by users of the MRP II production control system which also operates under the "push" philosophy.

Work-in-process inventory principally accumulates in two locations at the facility, bottlenecks and RFI pools. Bottlenecks, along with their excess inventory, occur when the arrival rate of material exceeds the capacity of the work center to process it. This can happen because of fluctuations in the repair process, in which case they are only temporary, or because the work center is capacity constrained.

Although engine inductions are scheduled to level load the facility, individual work center loading varies considerably. This fluctuation in loading is caused by the varying processing times associated with each component. Thus temporary bottlenecks continually appear in the facility as material is pushed through. These wandering

bottlenecks cause both work-in-process inventory to build up and repair time to increase.

Visual observation of the production process suggests three work centers are actually capacity constrained. Excessive levels of work-in-process inventory, which indicate the existence of a bottleneck, were observed on six separate occasions in the blade repair, rotor disassembly/assembly, and fuel control work centers. Quantitative identification of capacity constrained work centers can be done by summing requirements, however, the NADEP does not keep historical data on the number of items processed or actual repair time. Additionally, data would also be needed on the T-58 engine to compute work center loading.

The RFI pools accumulate inventory by their nature. This varies as a function of the number of engines inducted for repair and processing time for individual components. Although work-in-process inventory levels can not be quantified, Figure 7 shows the buildup of engines in work which suggests the magnitude of work-in-process inventory.

C. SUMMARY

Scheduling for the repair/overhaul of the T-64 is performed by inducting engines to level load the facility. Although level loading is a sound policy, by basing loading on inductions rather than repairs per quarter excessive work-in-process inventory can and does accumulate.

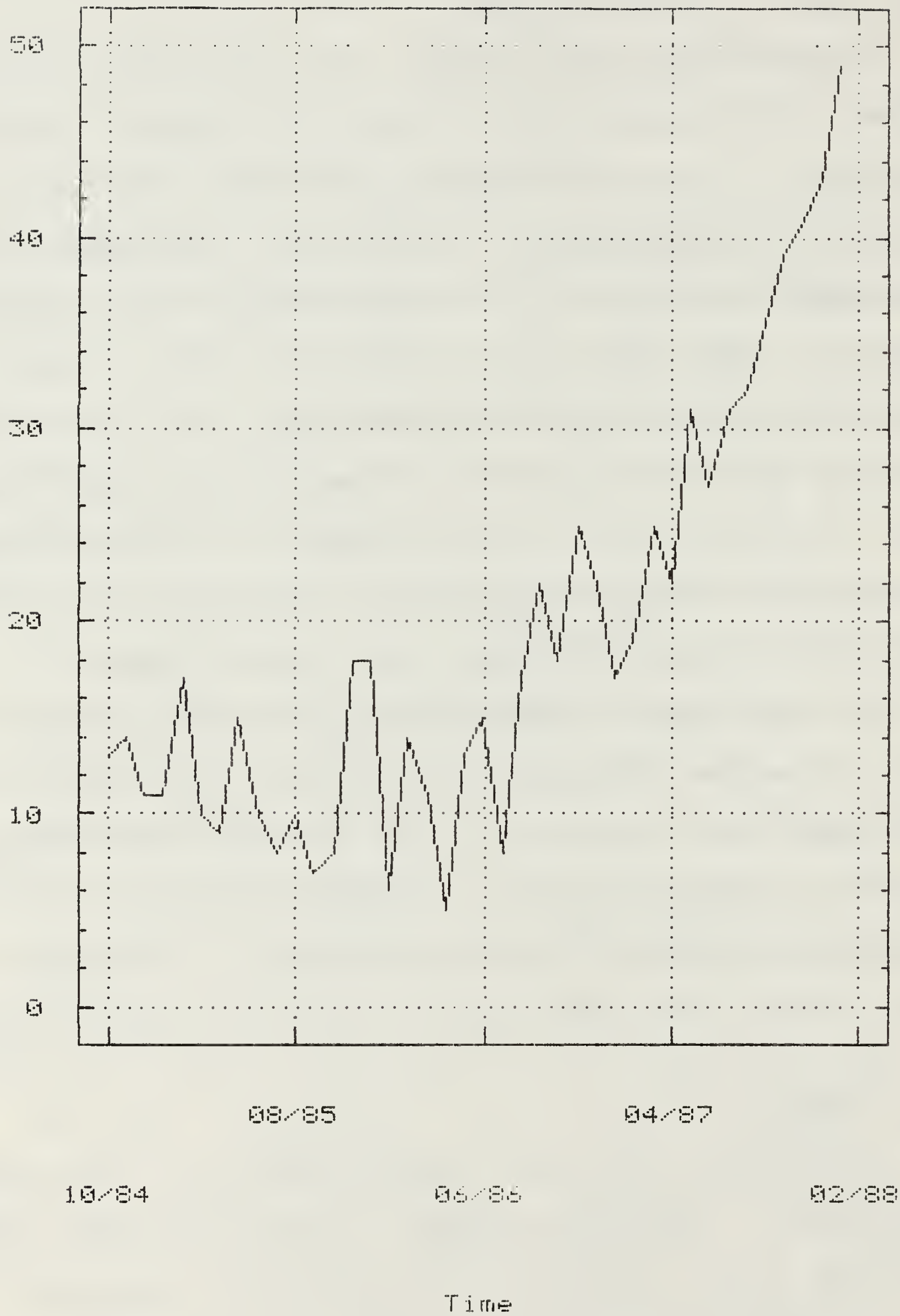

Figure 7. Time Sequence Plot of the Number of Engines in Work

The production of RFI engines is controlled by pushing components through the work centers to the final assembly shop. This technique causes both excessive work-in-process inventory to accumulate and repair time to be longer than necessary.

V. RECOMMENDATIONS

This chapter will present and discuss two recommendations that will decrease repair time, minimize work-in-process inventory, and reduce the number of engines awaiting maintenance.

An efficient production operation is one that strives to minimize processing time and work-in-process inventory while keeping costs down. As indicated in the previous chapter excessive work-in-process inventory and longer than necessary repair/overhaul times are currently problems at the T-64 engine facility.

To solve these problems many commercial production operations have adopted either Toyota's production system or OPT. Appendix A gives a detailed account of how these systems attack both problems. The principles espoused by these production planning and inventory control systems can be readily applied to the repetitive manufacturing process at NADEP, North Island.

A. SCHEDULE FOR REPAIRS PER MONTH VERSUS INDUCTIONS

Under current policy NADOC budgets for induction of a specified number of engines per quarter. It is recommended that the NADOC budget for completed engines per quarter. The engine planners could then set a master production schedule based on these numbers. Production would then

controlled based on the need to complete a given number of engines per month and the facility loaded accordingly. Production would then be keyed on the final assembly work center, and the second recommendation to implement a "pulling" type production system would be possible.

Additionally, as is demonstrated in the next chapter, a policy of inducting engines to maintain a repair rate significantly reduces the queue of engines awaiting maintenance.

B. ADOPT A "PULLING" TYPE PRODUCTION SYSTEM

With production keyed on final assembly, material can then be pulled as needed to complete an engine build up. Engines would be inducted and components repaired as required to meet the final assembly work centers' schedule. Adoption of this policy would stabilize repair time, engines would be produced as needed, and work-in-process inventory would be minimized.

Toyota's system is based on this principle and they as well as many other repetitive manufacturing firms have demonstrated impressive results. As noted in Appendix A, Toyota claims a 30 percent increase in productivity and a 60 percent decrease in work-in-process inventory.

Success of this type of system is dependent on the smooth flow of material between work centers at just the right time. Toyota accomplishes this through use of the "Kanban" system. Although this technique could be used in

some work centers it is not appropriate for the entire operation. While the repair process is basically a repetitive manufacturing operation, volume is low and the supply of most parts is governed by the induction of engines. This means that processing and transfer batch size will in many instances be one. Theoretically this is the minimum container and transfer lot size using the Kanban system, however in practice it does not work well.

A better approach is to use the philosophy behind OPT, that is to balance capacity by focusing attention on the critical resources. Implementation of a pulling type system will cause bottlenecks to develop as the final assembly work center demands parts. These work centers, if they are true bottlenecks, will ultimately limit throughput. Management can then focus its attention on these shops to ensure a smooth flow of material to the final assembly work center, increasing capacity when possible. Any shop that is not a bottleneck will only be loaded to ensure that the bottleneck operations are constantly utilized. To alleviate the problem of fluctuations in processing time a buffer of work-in-process inventory is maintained at these critical work centers. Excess manpower at non-bottleneck work centers can be used at the critical processes.

C. CONCLUSION

Adoption of a pulling style production control system keyed on the final assembly work center will decrease and

stabilize repair time as well as decrease work-in-process inventory. Additionally, as will be demonstrated by simulation in the next chapter, it will decrease the number of engines awaiting maintenance.

VI. EFFECT OF REPAIR RATE ON AWAITING MAINTENANCE QUEUE

This chapter will illustrate the effects of repair rate on the queue of awaiting maintenance engines at the NADEP. Through the use of a simulation and queueing theory, actual awaiting maintenance levels will be compared against the expected queue when different maximum repair rates are used.

Figure 8 illustrates a times series plot of the number of engines awaiting maintenance at the NADEP. As can be seen the queue has fluctuated between a high of 31 and a low of six, with the average being 16.5. This data will form the baseline against which the simulations and queueing model will be compared.

A. SIMULATION

This section will compare actual awaiting maintenance levels against those developed through a simulation using maximum repair rates of eight, nine, and ten engines per month. First, the simulation model will be presented followed by the data generated through its use. Lastly, a discussion of the results of the simulation is given.

1. Simulation Model

The simulation model is built upon historical data, used to calculate the arrival rate of engines needing repair and a specified maximum repair rate. This information is used to calculate the expected monthly awaiting maintenance

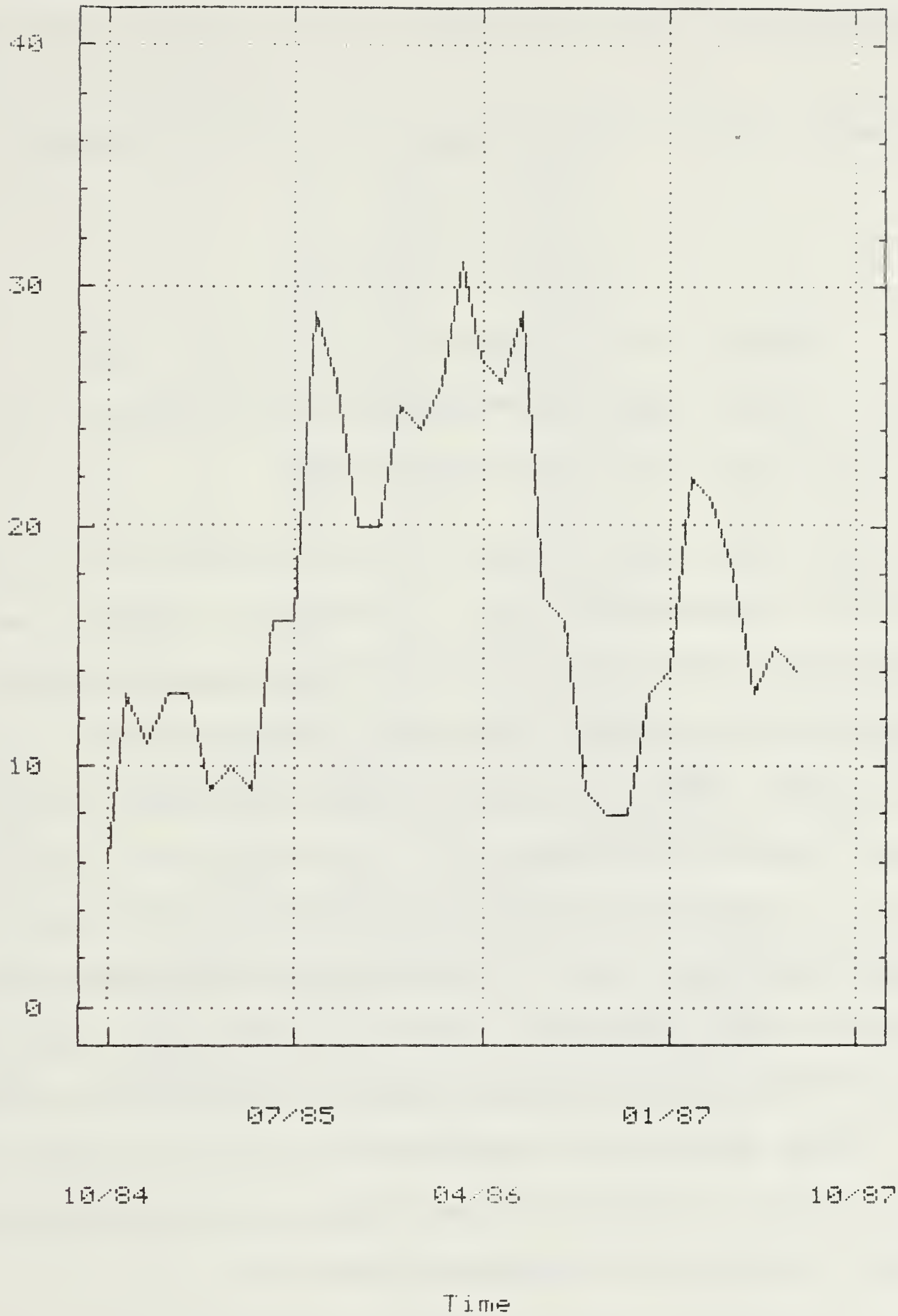

Figure 8. Time Sequence Plot of the Number of Engines AWM

queue for different rates of repair. The model is as follows:

$$AWM_c = AWM_l - (\text{Repair Rate, } 8,9,\text{or } 10) + Arrival_c$$

where:

AWM_c = Awaiting Maintenance Current Month

AWM_l = Awaiting Maintenance Last Month

$Arrival_c$ = Arrivals Current Month

Beginning with the October 1984 level of six engines awaiting maintenance, each successive month's awaiting maintenance level was determined using the above formula. A discussion of arrival rates and how the repair rates of eight, nine, and ten were chosen is given below.

a. Arrival Rate

Historical data on arrivals per month of engines to be repaired at the T-64 facility was not available. To calculate this historical data on the number of engines awaiting maintenance and the number inducted per month was used. This information was available from the weekly engine status reports prepared by the facility engine planners. The arrival rate per month was calculated by :

$$Arrival_c = AWM_c - (AWM_l - Inductions_c)$$

$Inductions_c$ = Inductions in current month

Table II below shows the calculated arrivals per month using the above formula and the historical data found in Tables III and IV of Appendix B.

TABLE II

Arrivals Per Month

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	5	13	6	13	4	5	8	7	12	7	16	5
86	7	4	9	9	4	9	6	5	9	0	7	5
87	8	2	10	5	15	6	8	0	9	8		

b. Repair Rate

In choosing the repair rates for the simulation historical data on engine completions per month, NADOC scheduled inductions and queueing theory were examined. First, queueing theory demonstrates that a service rate less than arrival rate will cause an ever expanding queue of items waiting to be serviced. Therefore, the service rate must be greater than the average arrival rate of 7.3 engines per month. To keep the simulation simplified whole numbers beginning with eight were chosen.

Secondly, a histogram of historical data on engine completions per month, Figure 9, shows that in a 40 month sample the facility completed eight or more engines per month 19 times. Nine or more completions were achieved

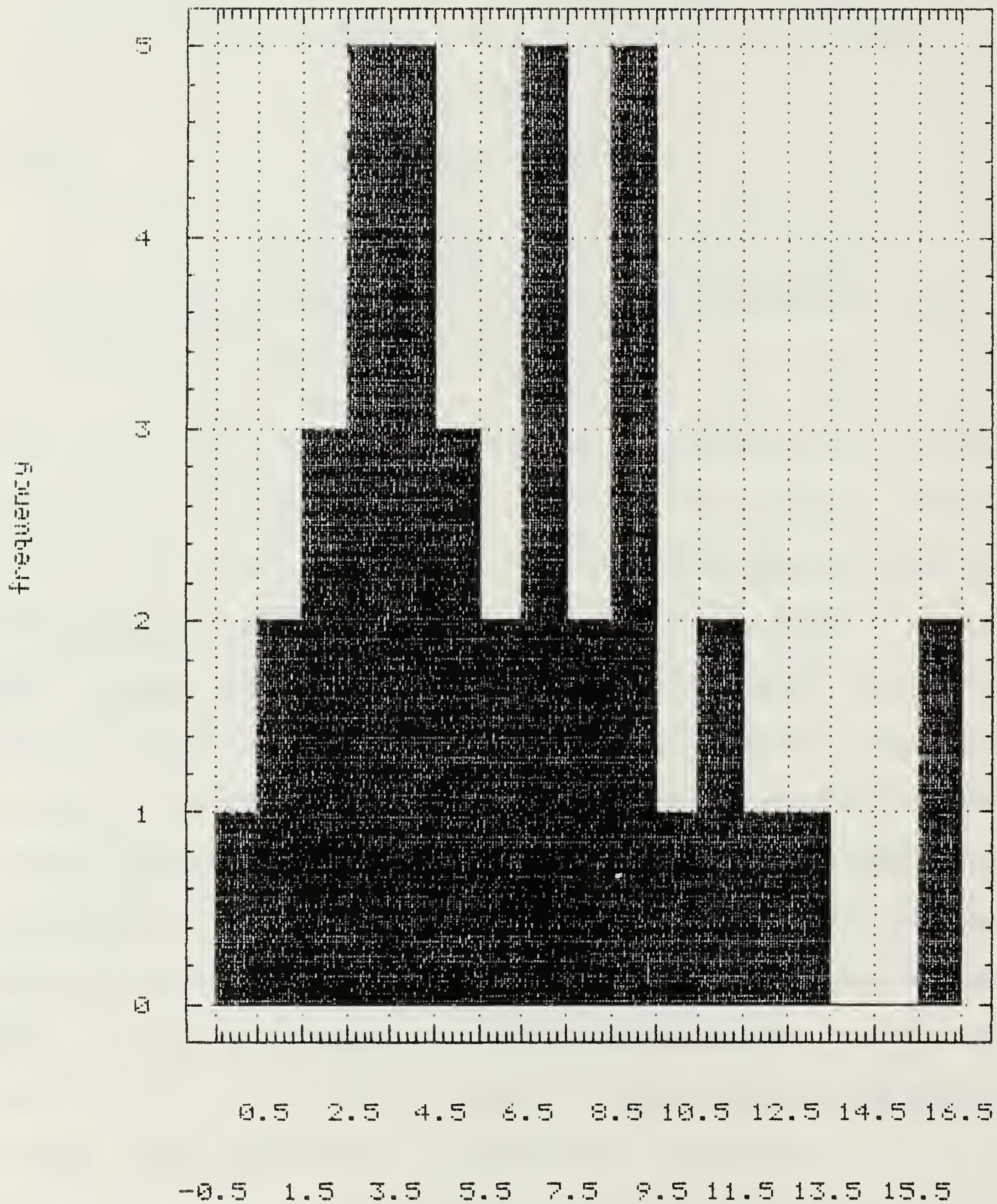

Figure 9. Frequency Histogram of Number of Engines Completed Per Month

14 times and ten or more were completed 12 times. From this information it appears that repair rates of eight, nine, and ten are within reason for purposes of the simulation. A detailed analysis of facility capacity would be needed to determine an exact estimate of the repair rate.

Thirdly, the number of engines scheduled for induction by NADOC, as presented in Table I, ranged from a low of 19 to a high of 37 per quarter. Figure 10 (a box and whisker plot, indicating minimum, maximum, and quartile values of this data) demonstrates that 50 percent of the values fall between 23 and 28.5 with the mean being 26. Therefore, expected failures and funding is available to adopt repair rates of at least eight or nine per month. Given this data, a repair rate of ten appears to be an upper limit.

2. Simulation Results

Figures 11, 12, and 13 show the results of the simulation as a time series plot of actual awaiting maintenance queues verses the queues that would have existed if a constant repair rate of eight, nine, and ten had been in use by the facility during the time frame of the simulation. Data tables for the simulation are in Appendix B.

As would be expected when a repair rate of eight engines per month is used it takes longer to reduce the already existing queue of engines and there is greater

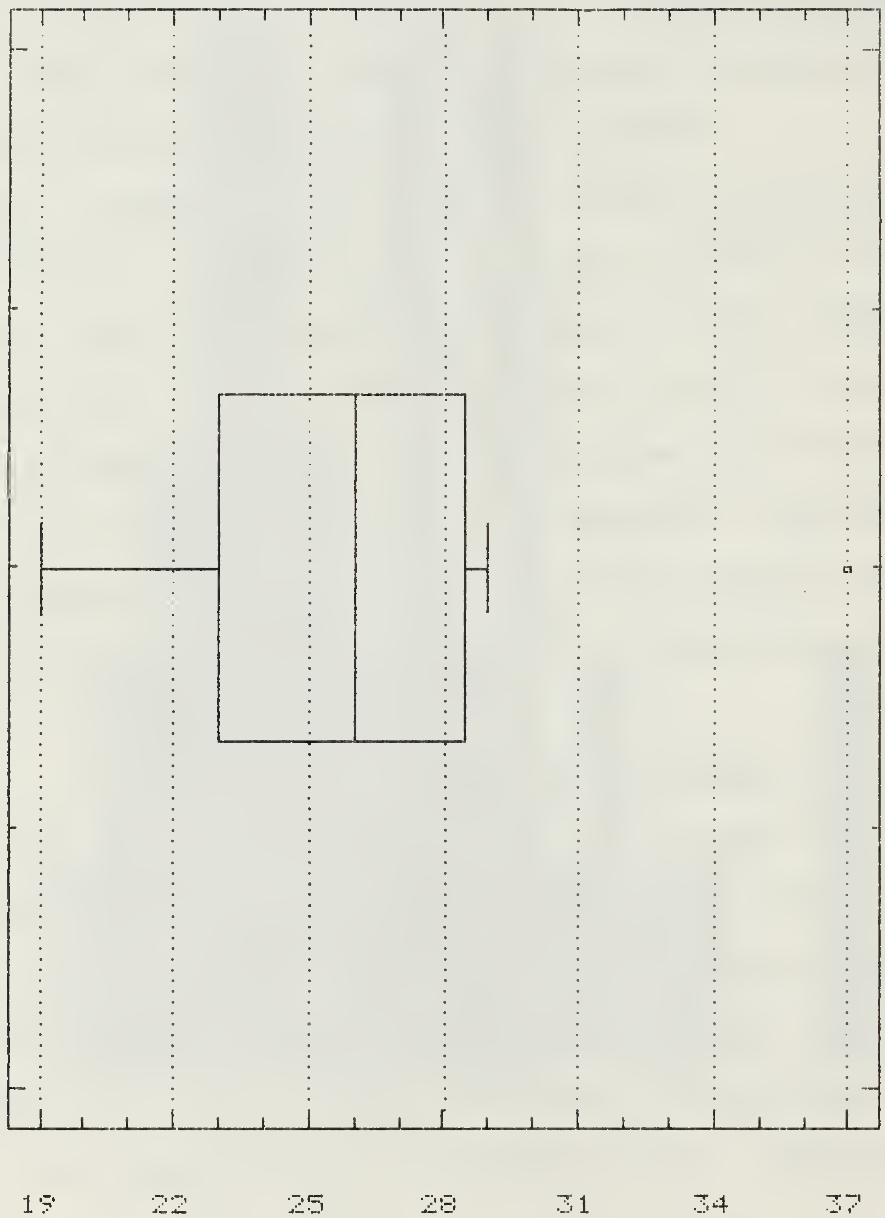

Figure 10. NADOC Induction Schedule per Quarter for FY 86, 87 and 88

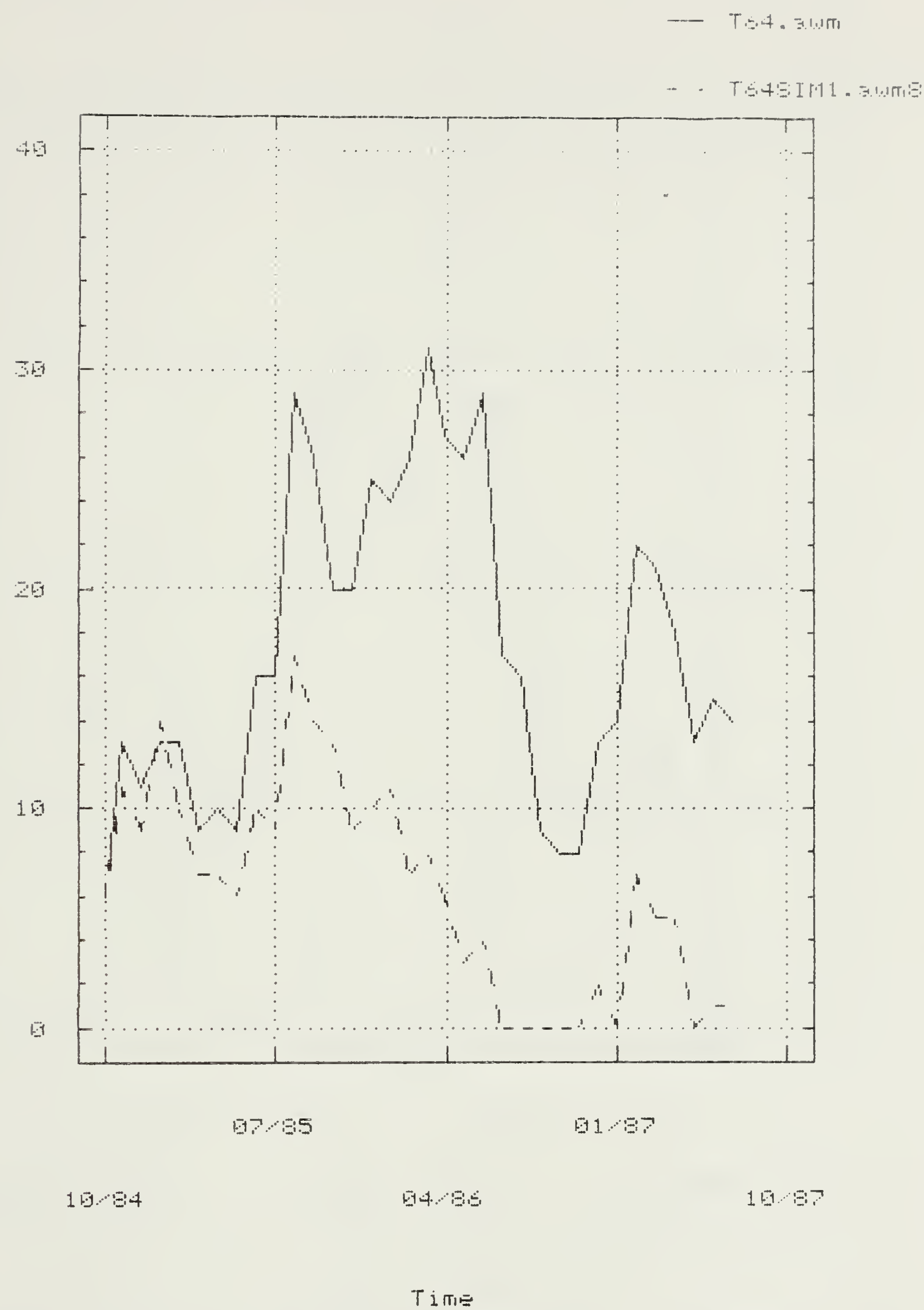

Figure 11. Time Sequence Plot of the Actual Number of Engines AWM vs. Simulated AWM Level with a Repair Rate of Eight per Month

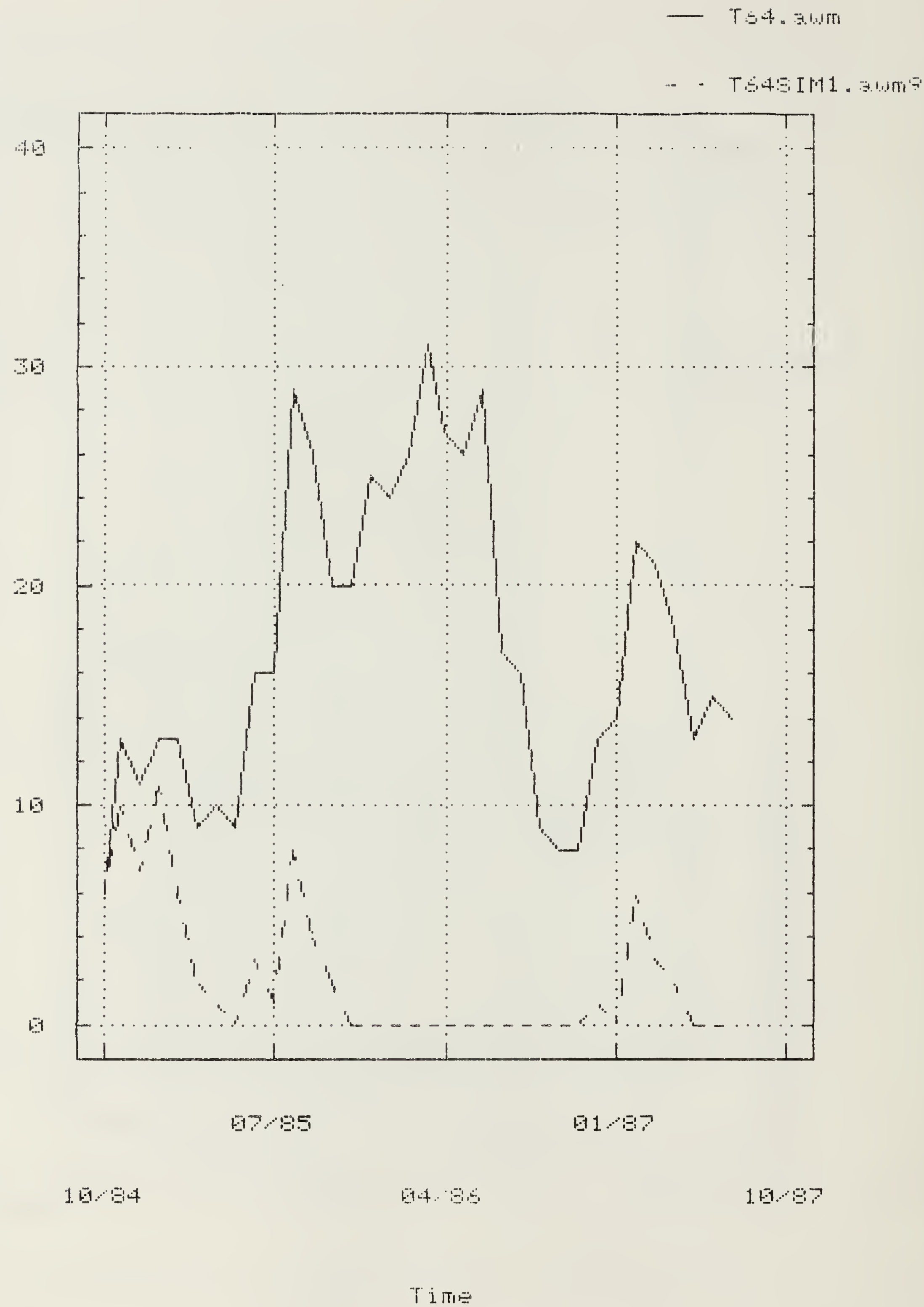

Figure 12. Time Sequence Plot of the Actual Number of Engines AWM vs. Simulated AWM Level with a Repair Rate of Nine per Month

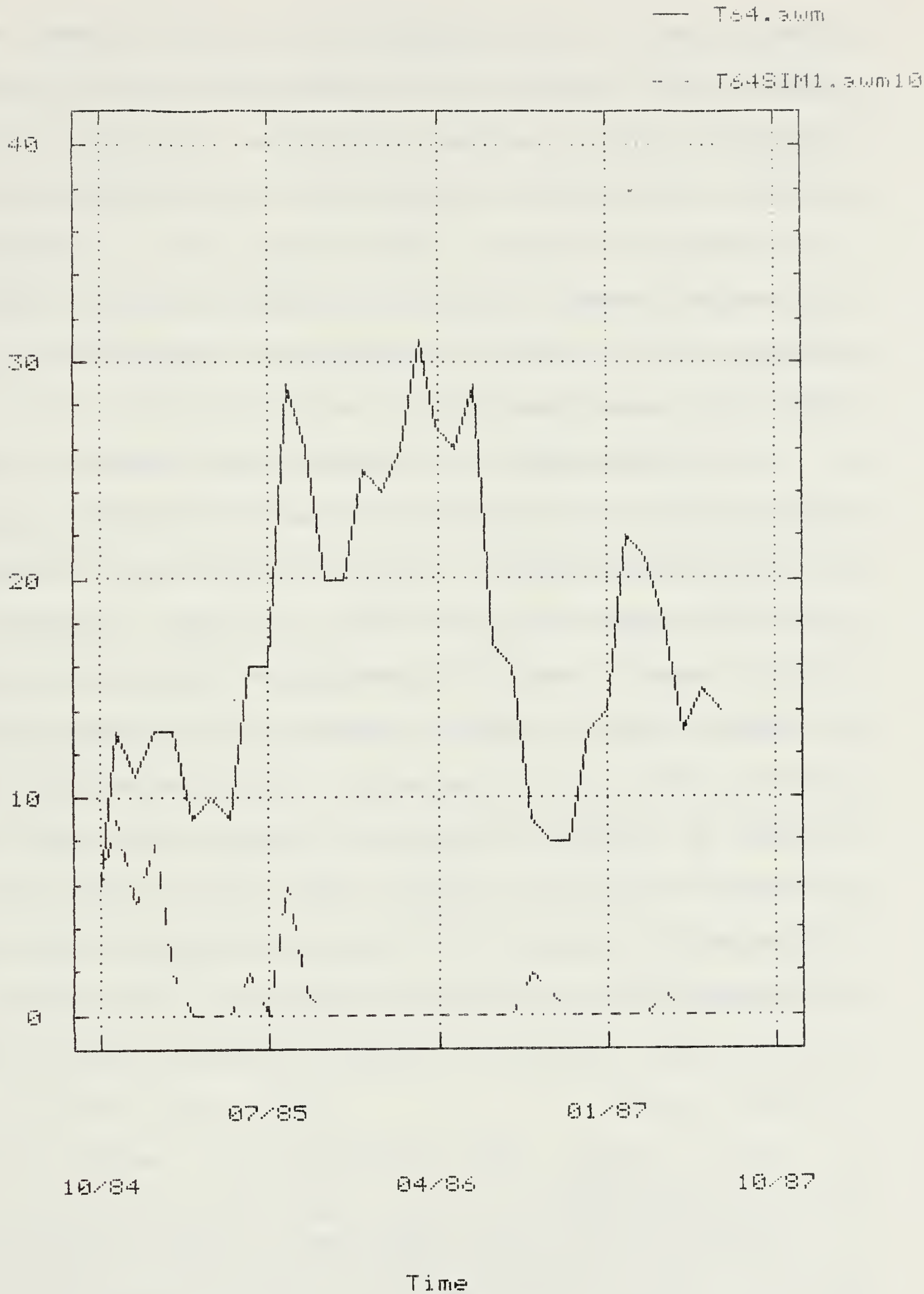

Figure 13. Time Sequence Plot of the Actual Number of Engines AWM vs. Simulated AWM Level with a Repair Rate of Ten per Month

fluctuation in the awaiting maintenance queue than for repair rates of nine or ten engines per month. However, in each case the queue is reduced to zero with occasional spikes. Of special interest are the peaks reached after the queue reduces to zero. When a repair rate of eight is used the maximum number of engines in queue is seven while levels of six and two engines in queue are reached when the repair rate used is nine and ten.

Comparing these results of the simulation against a mean of 16.5 engines in queue under the current system leads to two conclusions. First, by adopting the policy of inducting engines (if available) to ensure that the maximum repair rate is achieved the number of engines in queue will be reduced and a proportional increase in system level RFI engines will occur. Secondly, if the current level of RFI engines is optimal it would be possible to reduce the total system inventory of engines. The reduction possible can be estimated at between nine and 14 engines. This is the difference between the peaks experienced in the simulations and the mean number of engines held in queue under the current system.

B. QUEUEING MODEL

Queueing theory has developed a number of models that can be used to predict the average number of arrivals waiting service. These models are based on the characteristics of the system. The model used for this

section operates under the assumptions of a single channel waiting line, a single phase service system (which is one that has only one step), a constant service rate, an unlimited queue, and that the arrival rate is Poisson distributed.

These assumptions fit the repair system very well. Engines are delivered to the facility from a single channel which is the NAS North Island supply department. Although a number of actions are required to repair an engine, by looking at the repair itself as a single step the assumption of a single phase system holds. A constant service rate is an assumption made to illustrate its effect on queue length. No limit is placed on queue length so this assumption also fits. Lastly, is the assumption that the arrival rate is Poisson distributed. Analysis of the arrival rate data using a Chi-Square Goodness of Fit Test revealed that at a 95 percent confidence level the assumption that the data does not fit a Poisson distribution with a mean of 7.3 cannot be rejected. Therefore, for purposes of this analysis it is assumed that the arrival rate is Poisson distributed.

Given these characteristics the average number of engines awaiting maintenance can be calculated for a system with an arrival rate of 7.3 engines per month and service rates of eight, nine, and ten engines. The formula for computing these numbers is:

$$\bar{n}_1 = \frac{\lambda^2}{2\mu(\mu-\lambda)}$$

where λ is the arrival rate, μ is the service rate, and $\bar{n}_1$ is the average number of engines awaiting maintenance.

The calculations result in values for average queue length of 4.75, 1.74, and .98 engines awaiting maintenance when constant repair rates of 8, 9, and 10 respectively. Each of these values is well below the mean of 16.5 engines in queue under the current system. This further illustrates the possible reduction in engines awaiting maintenance that could be achieved by maintaining a specified repair rate.

VII. CONCLUSION

The conclusion will discuss the benefits of improved production planning and control procedures and recommendations for future work. Increased asset availability will be presented first, followed by a discussion of potential cost reductions. Recommendations for future work concludes the study.

Improvements in the production planning and inventory control system used in the depot level repair of the T-64 engine will directly benefit the Navy through increased asset availability and decreased costs.

A. ASSET AVAILABILITY

Availability of assets will be increased in two ways. First, a reduced mean time to repair causes a decrease in the number of engines in work at the facility and a proportional increase in RFI engines. The average number of engines in work being a function of repair rate and mean time to repair any reduction in mean repair time directly decreases the number of engines in work.

Although not quantified in the study the following example serves to illustrate this point. Assuming a repair rate of eight engines per month and an average mean time to repair of 30 days, which is the current average repair time for the facility, the average number of engines held in work

is eight. By reducing repair time ten percent to 27 days an average of 7.2 engines in work would be achieved.

Secondly, as illustrated by the simulation, maintaining a specified repair rate significantly decreases the number of engines awaiting maintenance. This also correlates to a proportional increase in asset availability.

B. COSTS

The three principal components of the cost function that are affected by improvements in the production planning and control system are repair, annual inventory, and investment costs.

Repair costs are partially a function of the length of time it takes to perform the repair. By minimizing the mean time to repair a decrease in repair costs will be realized.

Annual inventory and investment costs are directly related to the total number of engines procured and held in inventory. This level of inventory includes both RFI engines and those non-RFI engines in the repair cycle. If it is assumed that the current level of RFI engines is optimal then an increased level of RFI engines is not needed. Given this information total system inventory levels and cost can be reduced by reducing the number of non-RFI engines in the system.

The discussion of availability of engines above showed how the levels of RFI and non-RFI engines would change by improving production methods. If this increase in the

number of engines is not needed for readiness engines can be eliminated from the system and costs reduced.

This can be accomplished in two ways, either by using current RFI engines on new production aircraft or by not buying new engines as old engines are removed from the system because of attrition.

C. RECOMMENDATIONS FOR FUTURE WORK

This study has shown that substantial benefits can result by improving production planning and inventory control procedures. Emphasis in this area is needed throughout the depot repair system. Future studies could be extended to other depot repair processes.

Additionally, work in the following areas would be beneficial.

1. What is the actual capacity of the T-64 repair facility?
2. What levels of supply supported repair parts are needed to introduce a just-in-time production policy?
3. Is the current level of RFI asset optimal?

APPENDIX A

PRODUCTION PLANNING AND INVENTORY CONTROL SYSTEMS

This appendix will present the three prominent production planning and inventory control systems currently in use by industry today: Material Resource Planning II (MRP II), Toyota's Production System, better known as Just-In-Time, and Optimized Production Technology (OPT). A brief discussion of early inventory control systems will be given leading to an introduction of the MRP II system. Then Material Resource Planning II, Toyota's Production System, and Optimized Production Technology will each be discussed. Finally the systems will be compared.

A. EARLY CONTROL SYSTEMS

Early control systems used stock replenishment approaches to control inventory levels and smooth production. These included visual reviews, the two bin method, min/max levels, and statistical stock replenishment.

Visual review was a technique in which managers kept all usage data in their heads. The how much and when to order was based on experience. The two bin and min/max techniques are essentially the same thing. With the two bin method orders are placed when the first bin is emptied and the second opened. Min/max extends this to a minimum inventory level instead of bins. An order is placed when inventory is

depleted to the minimum level and an amount is ordered to return inventory levels to their maximum level. Statistical stock replenishment is better known today as the economic order quantity equation. First published by F.W. Harris in 1915 using constant demand, the equation has evolved to include stochastic demand. [Ref. 1] This technique balances inventory carrying costs against ordering costs to determine the quantity which yields the lowest total inventory costs. In 1934 Wilson repeated the equation and introduced a saw toothed curve based upon lead time and demand during the lead time which computed the order point for this method. [Ref. 1]

Around 1957 Joseph Orlicky observed that demand for certain parts was dependent upon the demand for other parts. [Ref. 1:p. 28] He categorized these demands as independent and dependent. First the independent demand is forecasted and then the dependent demand is calculated. It was from this observation that materials requirements planning was developed.

Given a master production schedule and the relationship between the independent and dependent items, the quantity dependent demand items is calculated. When this early version of MRP was introduced industry documented a 50 percent increase in inventory turnover using this materials requirements planning system. [Ref. 1:p. 30]

Next planners began to extend the scope of the concept to the other dependent requirements of labor hours, machine hours, capital, etc., that are necessary to support the master production schedule. At this stage materials requirements planning grew into manufacturing resources planning. Finally a feedback loop of actual results was added to update and continually revise lead times and quantities required. This "closed-looped manufacturing resource planning" is what is known today as MRP II.

Whether explicitly or implicitly, each of these techniques forecast demand during lead time and all attempt to provide safety stock to compensate for fluctuations in demand. As a result they suffer from false assumptions about demand and result in unnecessarily high inventory levels, stockouts and inventory imbalances. [Ref. 2:p. 6]

B. MANUFACTURING RESOURCE PLANNING II

MRP II is a three part system that begins with materials requirements planning, extends this to production resources and finally updates itself through a feedback loop.

1. <u>Prerequisites and Assumptions</u>

MRP II makes a number of assumptions and is based on a certain prerequisites. The first prerequisite is that a master production schedule exists for the independent demand item and that it can be stated in a bill of materials. It requires that this bill of materials precisely identify each inventory item by a unique code and is extended throughout

the manufacturing process. That is, as production proceeds each new sub-assembly takes on its own part number. The bill of materials then must not only list all the components of a given product but must be structured to reflect the manner in which the product is assembled.

Another prerequisite is the availability of inventory records for all items under the system's control. This file must be accurate, complete, and up-to-date if the MRP system is to be useful.

Four basic assumptions are made by the system. First, lead times for all inventory items are known and have fixed values. Second, every inventory item in the system goes into and out of stock. This allows for the monitoring of the manufacturing process from one stage to another. Third, all components of an assembly must be available at the time of assembly on the production line. Fourth, all work centers have unlimited capacity.

2. Mechanics

MRP II takes the master production schedule and determines the number of end items needed in each time period. This is then exploded into gross requirements for all materials by using the bill of materials. Next the gross requirements are adjusted for materials on hand by using the current inventory status records and net requirements are calculated as follows:

Net requirements = Gross requirements - [Inventory on hand - safety stock - Inventory allocated]

If net requirements are greater than zero, lot sizes are ordered with these being offset to allow for lead times at each step in the production process and supplier lead times. This is known as a push system because end items are pushed out by materials ordered and processed at an early date.

MRP II is capacity-insensitive, the fourth assumption outlined above. It only determines what is needed, when it is needed, and in what quantities. However the output from this first stage of the process can be used to calculate the required capacity of each work center within the production system. Roughcut capacity planning is now performed by comparing actual production capacity versus required capacity developed in this second step of MRP II. The output of this stage will tell planners whether a revision to the master production schedule is required.

Finally, as the production process takes place lead times and quantities required are updated by historical data to provide more accurate results.

3. Advantages

MRP II's principle advantage is that it is an outstanding materials requirements planning system. It can effectively be used to order materials and track work in process inventory through the production cycle.

4. MRP Shortcomings

MRP II has a number of drawbacks primarily due to the assumptions that it works under. First, by making the assumption that lead times are known and fixed, MRP does not allow for varying queue processing times. Queue time is a function of work center loading and can vary considerably. Longer than necessary average lead times are used for each work center to absorb this fluctuation. Using these average queue times results in a longer total lead time and the build-up of work-in-process inventory. Additionally, lot sizes are not dynamic. An entire lot must be processed before the next can begin, which also results in lead times that are longer than necessary and in work-in-process inventory.

MRP also assumes unlimited capacity in all work centers, whereas some work centers will usually behave as a bottleneck. As a result of this drawback repeated iterations are needed to schedule away overloads. This contradiction in the MRP scheduling logic makes it an ineffective capacity planning and controlling system. [Ref. 3:p. 9]

Finally, MRP is data intensive and requires strict discipline in keeping accurate records and making updates.

C. TOYOTA PRODUCTION SYSTEM

The "Toyota Production System," of which Just-in-Time production is a component, was developed by Mr. Taiichi

Ohno, a vice-president of the Toyota Motor Company. It is the primary production flow and inventory control system used by Japanese automobile manufacturers, their suppliers, and many other industries.

Encompassing all aspects of the production and inventory flow process, the Toyota production system covers process design, job design, job standardization, economic lot sizes, accelerated setup times, Just-in-Time production, autonomation, Kanban, Jidoka, Andon, and Yo-i-don [see below].

1. Just-in-Time Production

Possibly the most important aspect of the Toyota production system is the Just-in-Time concept. It is exactly what the name implies; production or delivery of a part occurs just when it is needed.

This production method accomplishes five principle objectives. First, it reduces work-in-process inventory. In Japanese plants of automobile manufacturers, inventory measured in days of production ranges from three to four days. [Ref. 4:p. 5] Second, lead time to produce a part is considerably reduced. The benefit of this is evident when design changes are necessary. Third, there is no surplus or "lost parts" which may have to be scrapped. Fourth, all parts are "visible," in process, at all times, making the need for expediting unnecessary. Finally, low inventory

levels significantly lower holding costs and the amount of capital tied up in work-in-process inventory.

To accomplish these objectives a "pulling system" is used. Each stage in the production process draws, "pulls," just the right amount of inventory from the preceding process to keep going. All production controls are keyed on the final assembly line. By connecting all of the work centers feeding final assembly in a chain fashion, the entire production process becomes synchronized with final assembly. The means of accomplishing this just-in-time, pull production process is achieved through the Kanban system of inventory control.

2. Kanban

Kanban denotes two types of activity in the Toyota production system. It is a system of material flow control and a system to improve productivity. [Ref. 5:p. 33]

Material flow control is accomplished by using cards called kanbans. There are two types of kanbans. "Conveyance" kanbans authorize the movement of parts from feeding to using work centers. "Production" kanbans authorize the production of parts to replace those withdrawn by user work centers. These are attached to the standard containers, which vary in size, used to move parts.

When a parts container is moved from a preceding operation stockpoint to its next operation, a conveyance card is attached to the full container and the production

card is removed and placed in a box at that stockpoint. This production card then becomes the authorization for the preceding process to produce another container of parts.

The inventory level between two successive processes is therefore controlled by the number of production and conveyance kanbans that exist between the two operations and the size of the standard container. The absolute minimum is one each, however this is usually not sufficient to provide smooth production so additional cards are added. During implementation a reasonable number of cards are used to start the process and then gradually withdrawn.

The rules associated with the system are as follows:

1. A kanban card must always be attached to containers holding parts.
2. The following work centers must always come to the preceding work center and pick the parts they need, never the other way around in a rush.
3. Never pick parts without use of the kanban cards.
4. The containers used should not exceed the number of production kanban cards in the system, and the quantity of parts picked by the subsequent work center should never exceed the number of conveyance kanban cards in the system. That way the total amount of inventory of that part can never exceed the amount authorized by the number of kanban cards in the system, and the amount of inventory in use can be controlled and reduced. [Ref. 5:p. 36]

Productivity improvements are made through changes in equipment, work design, materials movement improvements, minimizing kanbans, and container size.

3. <u>Implementation Requirements</u>

The successful implementation of the Toyota Production System involves the achievement of three

important objectives. First, every day's schedule must be nearly identical. Toyota levels its master schedule for a month. [Ref. 5:p. 36] Leveling means that each day's schedule for a month is identical. At the beginning of each month kanbans are issued according to that month's schedule and the work force adjusts manning and equipment to run this new daily schedule.

Secondly, equipment, work spaces, and the production process must be designed and arranged to provide a smooth material flow. Attainment of this objective is achieved by reducing setup and changeover times from one operation to another and through Yo-i-don. Redesign of machinery, tooling, and manufacturing processes, along with prepositioned changeover kits are means of achieving reduced setup and changeover times.

Yo-i-don is the coordinated production of parts into subsequent assemblies. The objective is to have each work station complete its task in a given time window so delays are minimized or eliminated. To keep track of material flow a light panel called Andon is used. If any one operation has difficulties its respective light will come on and operators on other operations will assist in relieving the difficulty. This will usually involve job standardization and the training of workers that are qualified to efficiently work at different operations.

The final objective that must be attained is defect-free production. Since Just-in-Time production is highly dependent on the flow of parts without delay, any disruption caused by a defective part causes major problems. Toyota uses autonomation, a word coined by their engineers, to achieve this goal.

Autonomation is the automatic identification of defects in the production process. This can be in the form of automatic inspection devices or inspection by workers themselves. In this system workers are responsible for inspecting their own work as well as that done by others on preceding operations. When a defect is spotted Jidoka, a term for production problem warning system, becomes operational. A switch triggers the Andon panel located above the production floor. A red light alerts the work force to a problem and the process is shut down until the situation is corrected. When the Andon is lit it becomes the responsibility of everyone in the vicinity of the work station to correct the problem.

4. <u>Productivity Improvements Process</u>

Productivity improvement is a cyclical process that begins with the issuance of kanban cards. Once the process is running smoothly some of the cards are withdrawn. Management and the work force then make changes to operate at this reduced inventory level. This reduces both cost and lead time.

Once the process is again running smoothly the cycle is repeated again by removing more kanbans. The key to success as the Japanese use this procedure is the assumption that the plant work force will strive to regularly improve productivity by minimizing kanbans and container size.

5. Advantages

Successful implementation of the Toyota Production System offers several significant benefits.

1. Inventory levels are drastically reduced.
2. Lead time is minimized. Therefore the system can react more quickly to changes.
3. Product quality is improved and scrap costs reduced.
4. Production is streamlined and relatively problem-free, because of its focus on problem solving.
5. The system promotes teamwork and adds dignity and responsibility to employees. [Ref. 5:p. 40]
6. A goal-setting mechanism is provided for both management and work force. [Ref. 5:p. 41]

Japanese companies using this system for five or more years reported close to 30% increase in labor productivity, a 60% reduction in inventory, and a 90% reduction in quality rejection rate, and a 15% reduction in necessary plant space. General Motors using the system since 1980 has slashed annual inventory-related costs from 8 to 2 billion dollars. [Ref. 3:p. 9]

6. Shortcomings

The requirements of the system put limitations on its application to industry and necessitate significant changes in the way a company operates.

First, the system only works for repetitive manufacturing processes. It cannot tolerate daily changes

in products that are produced or fluctuations in quantity more than plus-or-minus ten percent in the daily schedule. [Ref. 5]

Second, smaller and more-focused factories are required. Large unfocused production facilities are too complex to permit the system to succeed. [Ref. 6:p. 540]

Finally, not all parts can be controlled by kanban. Large components and raw materials need to be scheduled independently. [Ref. 5]

C. OPTIMIZED PRODUCTION TECHNOLOGY

Optimized Production Technology (OPT), developed in the early 1970's by Eliyahu Goldratt, was introduced in the United States in 1979. Marketed through Creative Output Inc. (COI), it is a software package that provides a complete system for production planning, materials planning, and resource scheduling. Because the logic used by the software is secret exact detailing of how the system works is not possible. However, the philosophy behind the system, its requirements and products can be presented.

1. Philosophy

The philosophy behind OPT is the key to understanding how it works. Goldratt stresses that manufacturing's purpose is to make money and to accomplish this,

> ...the company must simultaneously increase throughput, reduce inventory, and cut operating expenses. [Ref. 7:p. 13]

To achieve those objectives OPT focuses its attention on the critical resources that control output. Through use of the following nine rules production plans, materials plans, and resource schedules are produced that fully utilize critical resources, maximize throughput and reduce work-in-process inventory. [Ref. 8]

The first rule is that capacity not flow should be balanced. Queueing theory shows us that if we plan our resource requirements using average operation times such that expected utilization of resources is at or close to 100 percent operation times, queue lengths and flow times will get very large. [Ref. 9:p. 35]

Constraints determine non-bottleneck utilization, the second rule, addresses utilization of noncritical resources which is determined by the requirements of critical resources. The only resources that are utilized at 100 percent capacity are bottlenecks since they govern output. [Ref. 8] Non-bottleneck resources are scheduled to serve bottlenecks.

Excess inventory is attacked by the third rule, activation is not always equal to utilization. Output that can not get through a bottleneck is a needless buildup of work-in-process inventory.

Fourth, an hour lost at a bottleneck is an hour lost for the entire system. If a bottleneck is being fully utilized, time lost at this process can never be recovered.

Total throughput being governed by the bottleneck is therefore decreased. OPT uses work-in-process buffers only in front of bottlenecks and where the output of bottlenecks join other parts to ensure full utilization of capacity. [Ref. 10:p. 42]

Fifth, an hour saved at a non-bottleneck is a mirage. Anything done to save time at a non-critical resource will do nothing to increase throughput.

Intuitive in nature, the sixth rule is bottlenecks govern throughput and inventory.

Seventh, transfer batch should not always equal a process batch. Henry Ford used this rule in his assembly line process; his process batch was infinite while the transfer batch was one. [Ref. 8:p. 4]

Eighth, process batches should be variable, not fixed. Fixed lot sizes will not allow for balancing flow. Lot sizes are determined so that materials arrive at bottlenecks in such a manner that they are always efficiently utilized.

Ninth, set the schedule by examining all constraints simultaneously. By considering all constraints the planning and scheduling performed by OPT will not have to be changed constantly and will produce realistic results.

2. Requirements

OPT requires a detailed description of the production system and a master production schedule. Bills

of material, all possible routings, inventories, work center data, which includes setup and processing time, and available work hours are consolidated into a network for each end product.

OPT allows for specifying desired stock levels at each operation, maximum stock limits, minimum batch quantities, auxiliary machines, and scheduled delays. [Ref. 9]

3. Mechanics of System

Initially the data outlined above is entered into the system and a module called Buildnet is run. This links all the data together in a network. Figure 14 illustrates the entire process. Once the Buildnet function is completed the SERVE module, which takes into account the master production schedule, is run. This phase of the process is backwards scheduling procedure using order due dates and infinite resource capacity. Load profiles and average utilization are calculated for each resource.

Where bottlenecks occur, that is greater than 100% utilization, a module called SPLIT is used to divide the network into critical and noncritical resources. At this point the OPT module using Goldratt's secret algorithm is used. Considering each critical resource's finite capacity, it schedules the bottlenecks forward. At the same time it determines transfer and process batch sizes at each operation to balance the flow of products. SERVE then

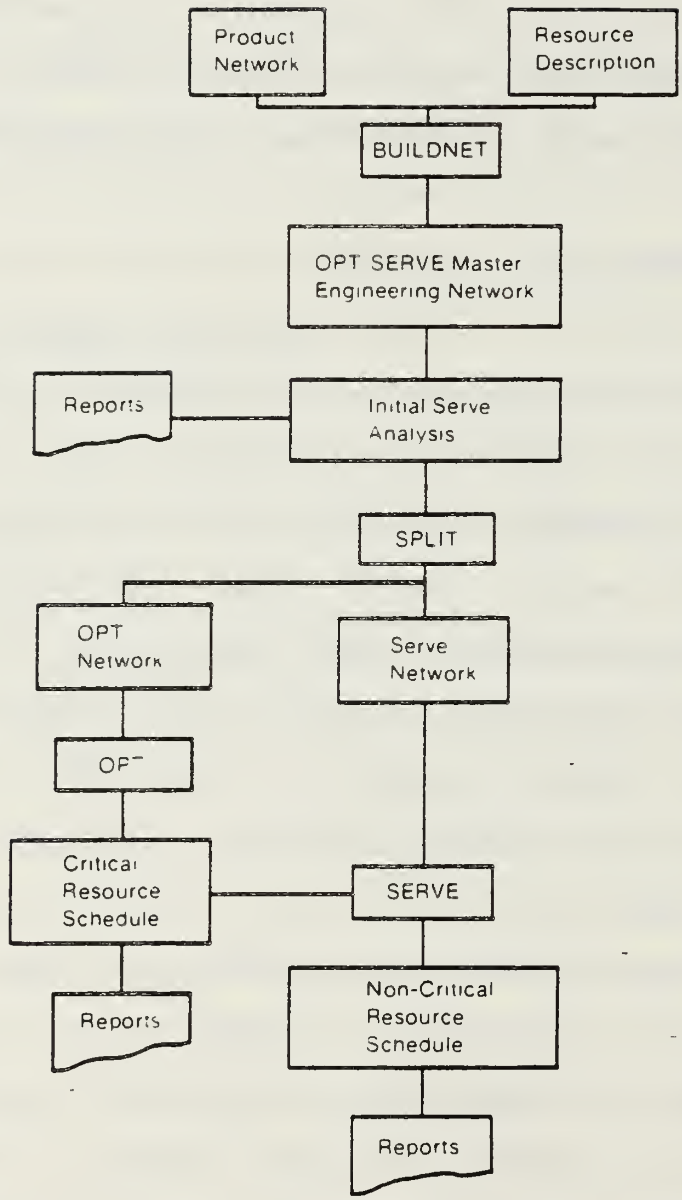

Figure 14. OPT Network

schedules the non-critical resources to ensure 100% utilization at all bottlenecks.

If non-critical resources now show 100% utilization they are moved to the critical portion of the network and a second iteration is run. [Ref. 7:p. 16]

4. Advantages

OPT's objectives to simultaneously increase throughput, reduce inventory, and decrease operating costs have been achieved.

> Howmet Turbine Factory, AVCO, Lycoming Division, and Bendix/Friction Materials each claim significant improvements in their manufacturing performance. [Ref. 7:p. 15]

Additional advantages include its detailed scheduling ability, and a reduction in priority conflict issues. [Ref. 10]

5. Disadvantages

The principal disadvantage is due to the data requirements necessary to develop and keep current each products network. Also, financial analysis systems would have to be changed. With increased setups and shorter run times efficiencies under the traditional system would appear to be terrible.

Lastly, because the logic is secret there could be an inherent resistance to trusting one's company's process to a system of which one has no technical knowledge to control.

E. COMPARISON/CONCLUSION

This section will provide a comparison of MRP II, the Toyota System and OPT. Production loading, batch sizing, materials flow, data requirements scheduling, flexibility, and quality control will be reviewed followed by a conclusion.

1. Production Loading

MRP II assumes infinite capacity and uses a two step procedure to correct this problem. Schedules are adjusted using the capacity requirement planning function.

The Toyota system and OPT assume finite capacity. Toyota uses kanban cards to control capacity and OPT uses bottlenecks.

2. Batch Sizes

MRP II assumes fixed batch sizes through all stages of production. Using economic batch sizing rules batches are larger than necessary and increase lead time.

Toyota attacks batch size problems by concentrating on reducing setup costs so that smaller batch sizes are economical.

OPT emphasizes reducing setup costs at bottlenecks and stresses efficient runs only at these critical resources.

3. Materials Flow

Work center delays can cause "wandering" bottlenecks in the production process. MRP II uses safety stock and longer lead times to absorb these statistical fluctuations.

Toyota forces the production process to stay in sync through its Yo-i-don philosophy and Andon system.

OPT uses safety stock in front of bottlenecks, while non-bottleneck resources have some amount of excess capacity to absorb fluctuations and meet the tight schedules developed by OPT.

4. Data Requirements

Toyota's need for data is almost zero, while MRP II and OPT require considerable amounts of accurate and continually updated data, OPT less so than MRP II.

5. Scheduling/Flexibility

Toyota's schedule is frozen for a month and cannot tolerate deviations of more than ten percent. OPT provides very detailed schedules which can be revised quickly. MRP II's schedules are not as detailed as OPT's and take longer to revise.

Minimum batch size and low inventory levels make Toyota's system flexible to changes in product or process design. Although OPT stresses minimized work-in-process inventory it is not as flexible as Toyota's system in this area, and MRP, because of its inherently large work-in-process inventory is the least flexible.

6. Quality Control

Toyota's is the only system that stresses worker involvement in quality control and productivity improvements. However, there is no inherent reason not to have worker involvement in the other methods as well.

7. Conclusion

Toyota's production system works very well in static repetitive manufacturing processes. It stresses quality and minimizes costs. However, it cannot be used outside of the repetitive manufacturing.

OPT includes many of the features of Toyota's system and can be used in both the repetitive manufacturing and job shop environments.

MRP does not appear to be an efficient production system. It performs material requirement planning well but lacks in the controlling and scheduling of production to minimize work-in-process inventories and lead times.

APPENDIX B

DATA TABLES

TABLE III

ENGINES AWAITING MAINTENANCE

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	6	13	11	13	13	9	10	9	16	16	29	26
86	20	20	25	24	26	31	27	26	29	17	16	9
87	8	8	13	14	22	21	18	13	15	14		

TABLE IV

ENGINES INDUCTED

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	9	6	8	11	4	9	7	8	5	7	3	8
86	13	4	4	10	2	4	10	6	6	10	8	12
87	9	6	5	4	7	7	11	3	7	9		

TABLE V

ENGINES AWAITING MAINTENANCE
SIMULATED REPAIR RATE OF EIGHT PER MONTH

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	6	11	9	14	10	7	7	6	10	9	17	14
86	13	9	10	11	7	8	6	3	4	0	0	0
87	0	0	2	0	7	5	5	0	1	1		

TABLE VI

ENGINES AWAITING MAINTENANCE
SIMULATED REPAIR RATE OF NINE PER MONTH

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	6	10	7	11	6	2	1	0	3	1	8	4
86	2	0	0	0	0	0	0	0	0	0	0	0
87	0	0	0	1	0	6	3	2	0	0		

TABLE VII

ENGINES AWAITING MAINTENANCE
SIMULATED REPAIR RATE OF TEN PER MONTH

FY	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
85	6	9	5	8	2	0	0	0	2	0	6	1
86	0	0	0	0	0	0	0	0	0	0	0	2
87	1	0	0	0	0	0	1	0	0	0		

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